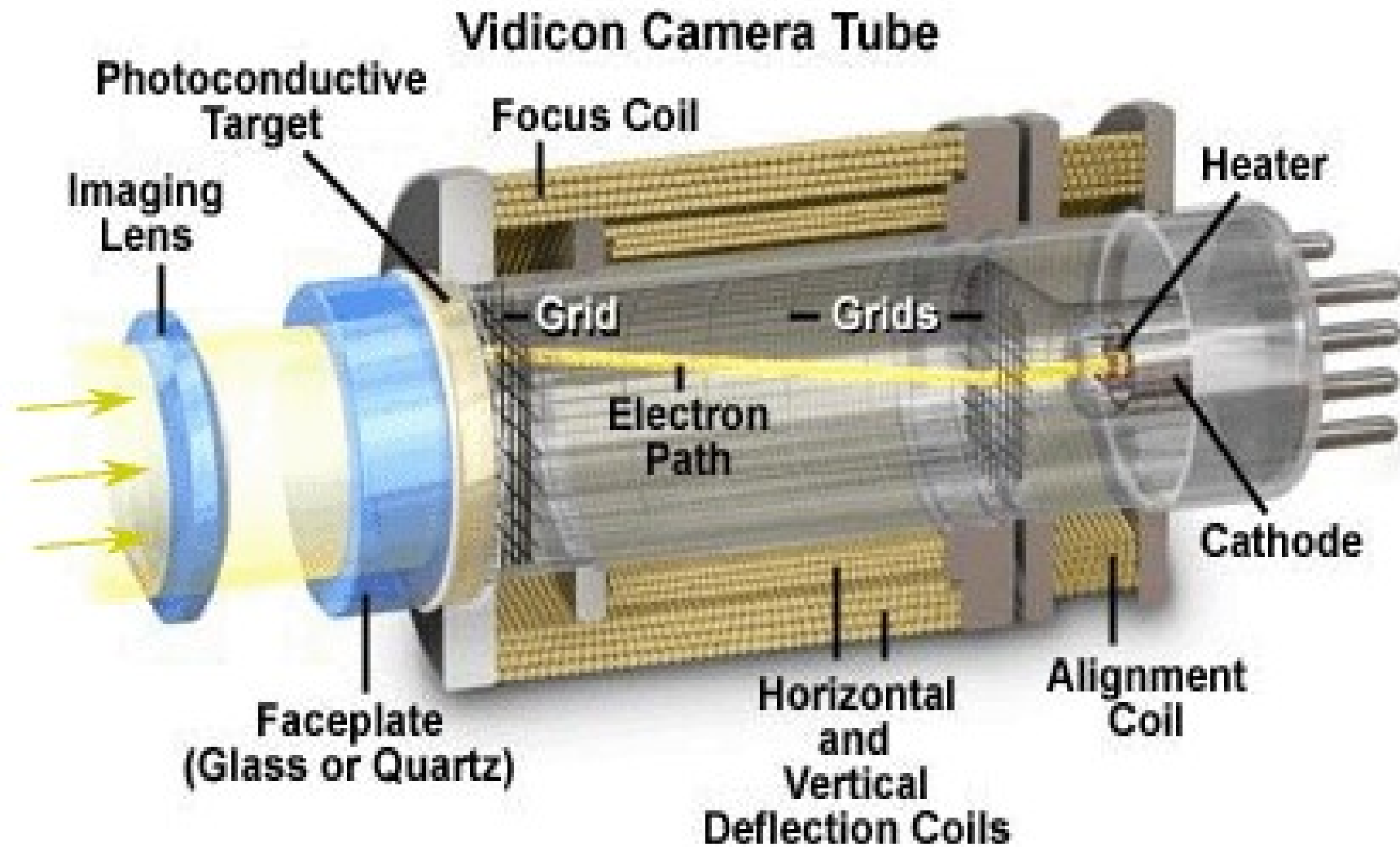


***Conference Summary:
Precision Astronomy
With Fully-Depleted CCDs***

Jim Gunn, Brookhaven 131109

Yesterday:



And a little later:

CHARACTERISTICS OF THE SILICON DIODE VIDICON

PHILIPPE CRANE AND MARC DAVIS

Joseph Henry Laboratories, Physics Department, Princeton University

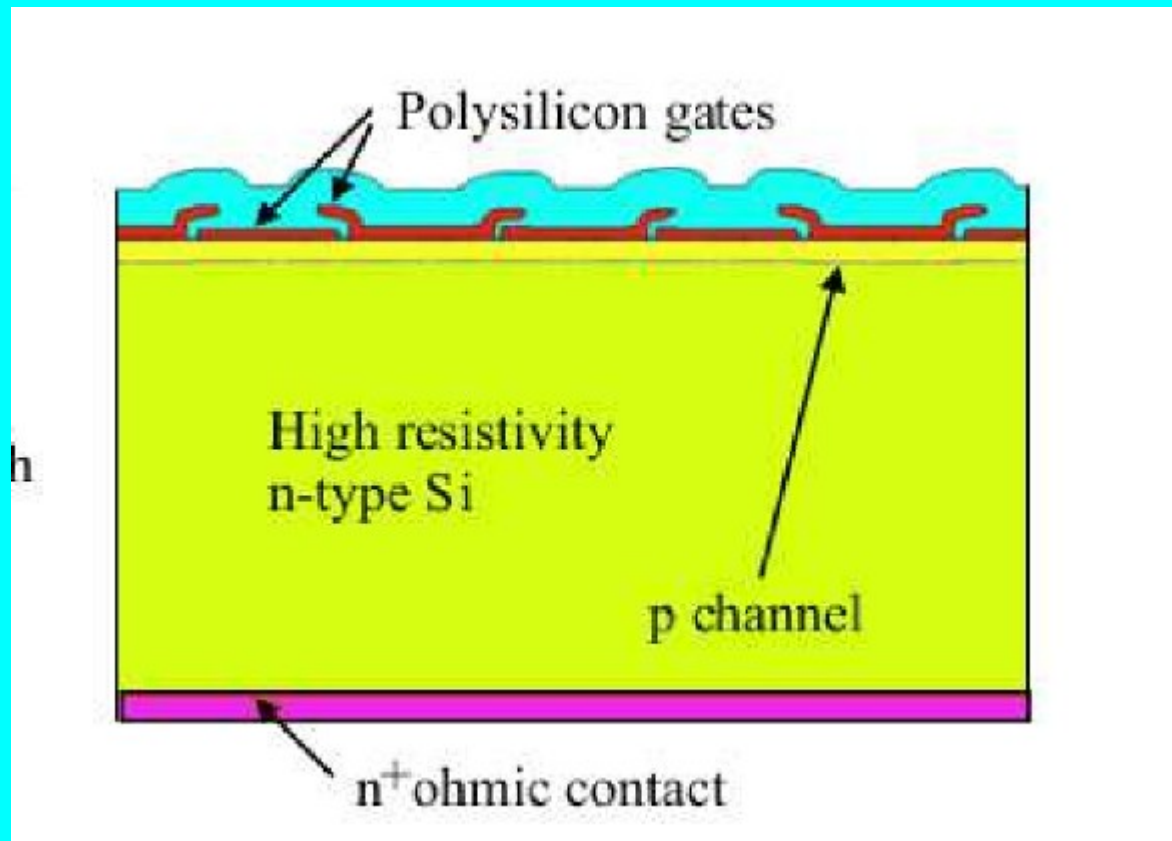
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A series of laboratory tests of the silicon diode vidicon has yielded valuable information of particular importance to astronomers. The vidicons were operated in slow-scan mode. The tests showed that these vidicons can be expected to operate with a dynamic range of 1000, a signal-to-noise ratio of 200:1, an MTF of 50% at 10 cycles mm^{-1} , and integration capabilities of several hours. The noise in the output does not appear to be limited by photon statistics, but is dominated by systematic effects. The results confirm that these devices are extremely good sensors for low-contrast high-optical flux problems in astronomy.

Key words: instrumentation — photometry

Characteristics completely dominated by electron optics.

Today we have fully-depleted CCDs, but the aspect ratio of Steve Holland's picture below is all wrong; the depth of the device is 10-20 times greater than the size of the pixel. (Bendable skyscraper)



We were so happy when CCDs came along: High QE, no more electron optics (!!--but we were wrong even for thin CCDs if we had looked/thought hard enough.) So we all need to get out our copies of Jackson (or Panofsky and Phillips) and dig in.

Small transverse electric fields in FD CCDs: The rebirth of electron optics in astronomical detectors

Bad news when a pixel is an order of magnitude taller than its size.

A photon is converted to a charge carrier at (u,v,z) in the silicon; the carrier is collected at (x,y) ; there is a map $(u,v) \rightarrow (x,y)$ with a Jacobian which maps elements of area

$$x = u + \alpha E_x$$

$$y = v + \beta E_y$$

and the transverse fields can arise from a large number of sources:

- 1. electrode geometry (edge fields, anti-blooming stops, applied electrode potentials)*
- 2. Doping variations in the silicon boule (tree rings)*
- 3. Self-induced fields from image charge interacting with itself or some electrode potential*

Chris told us about the direct effects of these fields on measurements:

***Shifts affect astrometry; derivatives affect shapes.
The Jacobian mimics QE variations and affects photometry
Image charge makes fat psfs for bright objects
charge trapped in/near channel stops causes `tearing'.***

Clear that we need to understand all the derivatives to understand shapes.

Charge generated by very bright light when devices are fully depleted can cause permanent damage, at least in p-channel CCDs.

Very difficult to separate Jacobian (pixel size) effects from real QE variations. (Some pixel size effects are from pixel sizes, NOT lateral electric fields, note... gate and implant irregularities, periodic errors in masks, etc...)

Need systematic approach, care in classification.

Hopeless mess??

NO, ALMOST CERTAINLY NOT.

***Gene and Gary told us about PanSTARRS and DES;
~1% photometry, 18mas astrometry for PanSTARRS
when corrections are applied.***

***For DES, systematic errors close to 1.5 mmag when treerings
are corrected, 10mas astrometry, probably atmosphere-
limited. Gate irregularity responsible for ~.003 pixel noise.
Exquisite stability.***

***SDSS: TDI, ~30mas astrometry, ~10mmag delivered photometry,
u band sensitivity changed by ~20% during 6-year survey,
cold and under vacuum essentially entire period.***

THINGS HAVE GOTTEN BETTER!!.

Calibration:

Flat fields serve as a transfer standard, NOT as gain standards. Corrections based on stellar photometry and independent data on device physics

Flats need to be stable and smooth, but it is in general not possible to either eliminate scattered light or to model it with necessary accuracy. (and scattered light in the flats is DIFFERENT from scattered light in data).

Model fields from treeerings, derive Jacobian. Correct. Can do with high precision – 5 mmag or better photometry, millipixel astrometry.

Fat PSF size is linear in flux

But caveats—mysterious low-level nonlinearity, a disaster for spectroscopy, but only in some devices.

Fat PSFs are predictable, but anisotropic...factor of ~3 higher correlation along columns than along rows.

Diffraction from gate structures at long wavelengths where chip is becoming transparent, also anisotropic.

LOTS of worries about shapes.

Satoshi --- HSC on Subaru

Largest camera to date – pathfinder for LSST

f/2.2, 100+ CCDs, ~ 1GPix

***400mas FWHM with very complex corrector,
excellent uniformity over full 1.5-degree field***

***Currently in commissioning, 300-night survey begins next
year.***

***Typical new-instrument teething problems, no really serious
problems yet.***

Andy—Found his copy of Jackson

Phenomena make sense with sensible parameters, but semi-phenomenological model for geometry and charge distribution.

Equivalent charges ~full well

***To do accurately, MUST understand 3-D geometry of device
Gate geometry and irregularities, at least statistically
Channel stops depth and *connectivity****

Internal fields are complex --- NOT uniform in depth because of potential pinning on both surfaces. Chromatic effects from conversion depth interact with this.

Methodology – Challenge, in my view, is to find fast, *sufficiently* accurate ways to solve electrostatic problem.

Tidbit—Treerings and fringing appear to be correlated. Physical properties (polishing?) refractive index????

Steve – Builds devices

So he has device details – still needs to find Jackson, but can make accurate models.

Maybe we need to be sure we have these details for our CCDs???

Pierre—Couldn't find his Jackson

Phenomenological model

Assume linearity in charge, model correlations

Must assume symmetries, regularity

Use correlation to predict fat PSFs – reasonably successful

No need to extract secrets from CCD manufacturers

Which way??

Images and Image Processing

Observed x,y image in CCD

---> u,v image `on' silicon (electrostatics, ??)

---> α, δ image on sky (optics, atmosphere)

all affected by filter response, QE, SED, brightness and SB distribution of sources

Paradigm of CCD images being perfect representations is (already was) clearly broken.

Need to keep at least

- 1. Signal (pixel flux)***
- 2. Location of pixel***
- 3. Size and shape of pixel (need Jacobian MATRIX, not just determinant.***

Scale? Separable large-scale and small-scale effects?

Or just bite the bullet?

Effects ARE small, and probably we do not need exact treatment.

Task is to find algorithmically practical solutions.

Science

Erin reminded us that the MEASUREMENT of shear, even with perfect images, is not a solved problem

Depends on excellent statistical understanding of the shapes of galaxy images. Forward modeling is subject to model bias, and this is likely to be dominant.

Josh Meyer and Pat remind us that these shapes and their measurable properties depend on wavelength, and the observed images depend on details of the galaxy SED, and these chromatic effects are almost certainly large enough to be a large or dominant effect with real images. No color gradients yet, but MAY not be important.

Nothing, really, to do with CCDs, but these problems need to be solved independently even with perfect CCDs.

The Way Forward

Effects are understood *semi*-quantitatively.

Interesting and encouraging that we have learned so much from astronomical data

BUT

Surely better to learn under controlled conditions in the lab. Still some real question about how to do these experiments.

Learn much from flats, but not everything. Need efficient way to characterize pixel shifts. Perhaps gratings?

Other sources – X, gamma, muons – Juan

I am personally dubious about `accurate' astronomical images, but exploration of the distribution of surface brightness and shapes may require this. Need to do proper sizes, shapes, AND backgrounds.

WE ARE NOT DONE WHEN THE DETECTORS ARE BUILT AND DELIVERED. Keep studying.

Challenges

Chris urged us to learn to speak the same language, and to be a bit precise (glowing edge, indeed !!!)

Most of what we have discussed is 'just' electrostatics, but the source of the fields is very varied

Need classification and agreement about what we are talking about, and discussion needs to cross fabrication, electronics, testing, astronomy, simulation, software

What is going on at low light levels? Need to understand for spectroscopy, and for very low light-level imaging. Amplifiers are getting better, so we need this.

But most of all, need work in all these sectors to understand the detectors as well as possible at EACH stage, but especially before they reach the telescope.

